COMPUTATIONAL STUDY OF SHEAR STRENGTHENED OF RC CONTINUOUS BEAM USING CFRP SHEET WITH DIFFERENT WRAPPING SCHEME

MHIMED RAMADAN OM BALKOU

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

DEDICATION

This thesis is dedicated to my supervisor Professor Dr. Abdul Aziz bin Abdul and to my father (RAMADAN MO BLKOU) who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother who taught me that even the largest task can be accomplished if it is done one step at a time finally to my old brother and has son.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ACKNOWLEDGEMENT

First I would like to thank Allah for his blessings and for helping me achieve success in every endeavour of my life. I would also like to thank my parent's father and mother, my brother and sisters for their unconditional love, guidance career.

I would like thank my supervisor; Professor Dr. Abdul Aziz bin Dato Abdul samad for his support and guidance throughout the duration of my project. This research would have certainly been much more difficult without his expertise and knowledge on the subject.

Special thank go to Noorwirdawati Ali her assistance throughout for this research project. Her help made the task much easier.

The last but not least I would like to thank UTHM University and specially Department of Civil Engineering to give me opportunity to study the master degree.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Nowadays the using of carbon fiber reinforced polymer CFRP composites as an externally bonded reinforcement has become one of the alternatives solutions to repair shear defect on reinforced concrete structure. Therefore, this research intended to study and investigate the effectiveness of using externally bonded CFRP strips in strengthened RC continuous beams, as well as to study the behavior of RC continuous beams repair with CFRP strips for initially strengthened. A total of five RC continuous beams with size of 150x350x5800 mm was simulated and involves 0/90 degree orientation of CFRP strips in fully wrap schemes (4 sides and 3 sides). Five beams was analyzed by using ABAQUS software. The analysis results indicated that of externally bonded CFRP strips has enhanced the shear capacity of continuous RC beam. The numerical results also show good agreement with the experimental.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Nowadays the using of carbon fiber reinforced polymer CFRP composites as an externally bonded reinforcement has become one of the alternatives solutions to repair shear defect on reinforced concrete structure. Therefore, this research intended to study and investigate the effectiveness of using externally bonded CFRP strips in strengthened RC continuous beams, as well as to study the behavior of RC continuous beams repair with CFRP strips for initially strengthened. A total of five RC continuous beams with size of 150x350x5800 mm was simulated and involves 0/90 degree orientation of CFRP strips in fully wrap schemes (4 sides and 3 sides). Five beams was analyzed by using ABAQUS software. The analysis results indicated that of externally bonded CFRP strips has enhanced the shear capacity of continuous RC beam. The numerical results also show good agreement with the experimental.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CONTENTS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

1.0 Introduction.

Many of the existing reinforced concrete (RC), steel, and masonry structures throughout the world are in urgent need of repair or reconstruction because of deterioration due to corrosion of their steel reinforcements, various environmental factors, seismic loading, an increase in service loads, and/ or growing amount of traffic. Moreover, during the modernization of buildings, the removal of individual supports and walls may lead to a redistribution of forces and the need for strengthening of structures. Fiber reinforced polymer (FRP) rebar have been the subject of a significant amount of research in current years. Researchers have found that one of the major drawbacks to FRP reinforcement is their brittle failure at ultimate tensile strength. When FRP reinforcement is used as reinforcement in concrete, sudden failure of the reinforcement bars can lead to brittle structural failures (Nabila, 2001)**.**

Strengthening of reinforced concrete structures using externally bonded carbon FRP sheets is an effective method of improving the structural performance under both service load and ultimate load. Strengthening with externally bonded FRP sheets has been shown to be applicable to many types of RC structures. Currently, this method has been implemented to strengthen such structures as columns, beams, slabs, walls, chimneys, tunnels, and silos. The uses of external FRP reinforcement may be generally classified as flexural strengthening, improving the confinement and ductility of compression members and shear strengthening (Khalifa, 1999)

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.1 Problem statement

For many years concrete has been used as a preferred material in many structures including buildings, bridges, pavements, sewer and storm pipes, liquid holding tanks and others. Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning of distress. In several occasions existing RC beams have been found to be deficient in shear and in need of strengthening (Khalifa 1999).

Conventional shear strengthening methods such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very costly, requiring extensive equipment, time, and significant labor. The aging infrastructure worldwide has prompted many researchers and organizations to seek and techniques to revive the deteriorating and deficient structures. Advanced composite materials, known as fiber reinforced polymer (FRP) composites, have received significant attention as one of the most promising materials for use as external reinforcement in repair and strengthening of reinforced concrete (RC) structures. Also fiber reinforced polymer (FRP) composites offers significant advantages such as flexibility in design, ease of installation, reduced construction time, and improved durability.(Feras 2007)

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.2 Research objectives

The overall objective of this study program will to investigate the shear performance and modes of failure of RC beams after strengthening with externally bonded carbon FRP (CFRP) sheets .More specific objectives were to:

1) To investigate the effectiveness of using externally bonded CFRP strips in repair RC continuous beams.

2) To study the behavior of RC continuous beams repair with CFRP strips wrapping schemes (4 sides bonding and 3 sides bonding) for initially strengthened
3) To compare the experimental results of repair continuous beams using CFRP strips with computational study using finite element modeling.

1.3 Scope of Research

The research scopes of this study are as following:

1) This study involves an experimental work and computational study on five RC continuous beams with identical size of 150 x 350 x 5800 mm.
2) All beams have an identical reinforcement details including stirrups and longitudinal reinforcement.
3) All beams were design to fails in shear.
4) The type of FRP will be used is bidirectional CFRP sheet.
5) The compressive strength of the concrete is 30 N/ mm^2.
6) ABAQUS will be used to analyses all data and will be compared with the experimental study.

1.4 Significance of Study

Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning of distress. In several occasions, existing RC beams have been found to be deficient in shear and in need of strengthening (Jayabrakash, 2006).

The previous specific goals were to address the factors affecting the shear strength, and to propose a design approach for computing the shear capacity of the strengthened beams. Conversely, the relatively new alternative strengthening technique

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

using advanced composite materials, known as fiber reinforced polymer (FRP), offers significant advantages such as flexibility in design, ease of installation, reduced construction time, and improved durability.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 2

LITERATURE REVIEW

2.1 History of FRP

The development of FRP rebar can be traced to the expanded use of composites in the post World War II era (ACI, 2001). The lightweight, high-strength characteristics quickly made the material popular in the aerospace industry. In the 1950's and 1960's, the United States, the former Soviet Union, and the United Kingdom were undertaking research projects to more broadly implement the use of FRP.With the expansion of the national highway system in the United States and the subsequent use of de-icing salts, corrosion of the reinforcing steel in pavements exposed to de-icing salts and marine water began to manifest itself as a problem.FRP reinforcement was not considered a viable alternative nor was it commercially available until the late 1970's. The first solutions to the corrosion of pavement reinforcement were galvanized coatings, powder resin coatings, polymer-impregnated concrete, epoxy coatings, and GFRP rebar. Technologically, in the 1980's, the demand for nonmetallic reinforcement has increased.

Due to its non-conductive and magnetically transparent characteristics, FRP reinforcement began to be used in concrete surrounding MRI equipment. During the

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1990’s, the deterioration of aging bridges in the United States and discovery of corrosion in some commonly used epoxy coated rebar again brought FRP reinforcement to the attention of the design and research communities as a possible solution to corrosion problems of reinforced pavements (ACI, 2001) (Vellore S , 2007).

2.2 The types of FRP are

2.2.1 Glass fibers

These are fibers commonly used in the naval and industrial fields to produce composites of medium high performance. Their peculiar characteristic is their high strength. Glass fibers typically have a Young modulus of elasticity (70 GPa for E-glass) lower than carbon or armed fibers and their abrasion resistance is relatively poor. In addition, a glass fiber has low fatigue strength.. To enhance the bond between fibers and matrix, as well as to protect the fibers and moisture, fibers undergo sizing treatments acting as coupling. Such treatments are useful to enhance durability and fatigue performance (static and dynamic) of the composite material. FRP composites based on fiberglass are usually denoted as CFRP (Liu 2007).

2.2.2 Carbon fibers

Carbon fibers are used for their high performance and are characterized by high Young modulus of elasticity as well as high strength. They have an intrinsically brittle failure behavior with a relatively low energy absorption; nevertheless, their failure strength are larger compared to glass and armed fibers. Carbon fibers are less sensitive to creep

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

rupture and fatigue and show a slight reduction of the long-term tensile strength. FRP composites based on carbon fibers are usually denoted as CFRP.

2.2.3 Aramid fibers

Aramid fibers are organic fibers, made of aromatic polyamides in an extremely orient form. Due to the anisotropy of the fiber structure, compression loads promote a localized yielding of the fibers resulting in fiber instability and formation of kinks. Aramid fibers may degrade after extensive exposure to sunlight, losing up to 50 % of their tensile strength. In addition, they may be sensitive to moisture. Their creep behavior is similar to that of glass fibers, even though their failure strength and fatigue behavior is higher than CFRP. FRP composites based on aramid fibers are usually denoted as CFRP. For strengthening purposes in civil engineering carbon fibers are the most suitable (Liu 2007).

2.3 Advantages of FRP

The advantages of FRP are:

1- Reduced construction time.
2- Corrosion resistance.
3- Flexibility in design.
4- High durability.
5- Ease of installation.
6- High strength-to-weight ratio.
7- High longitudinal tensile strength (Carlo Pellegrino 2009).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

2.4 Disadvantages of FRP

The disadvantages of FRP are:

1- FRP reinforcing composites are typically brittle materials.
2- The ultimate tensile strength of FRP reinforcing bars decreases with bar diameter.
3- Theoretical methods are not currently available to predict the bond properties and durability characteristics of FRP rebar with convenient accuracy.
4- FRP rebars can be used at service temperatures below the glass transition temperature of the polymer resin system utilized in the bar.
5- New unfamiliar failure mechanisms are possible particularly in FRP plate bonding and specialist survey should be provided (Carlo Pellegrino 2009).

2.5 Shear strength of Reinforced concrete using FRP

Shear failure of reinforced concrete RC beams is catastrophic and could occur without any forewarning. Many of the existing reinforced concrete (RC), and masonry structures throughout the world are in urgent need of repair or reconstruction because of deterioration due to corrosion of their steel reinforcements, insufficient shear reinforcement resulting, design errors, use of outdate codes, increase in demand of service load, and construction defects and design faults .

The application of Carbon Fiber Reinforced polymer Composite material, as an external reinforcement is a viable technology recently found to be worth for improving the structural performance of reinforced concrete structures (Chu kia wang, sixth edition ,1998)

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

2.5.1 The equation used to calculate shear strength

2.5.1.1 ACI Code provisions for shear strength of Beams

The nominal shear strength Vn is

$$V_n = V_c + V_S \qquad \text{Eq (2.1)}$$

Where.

Vc is the nominal shear strength provided by concrete.
Vs is the nominal shear strength provided by steel shear reinforcement.
Therefore, ACI 318-95 allows the use of the following simplified equation.

$$Vc = \frac{1}{6}\sqrt{f'c}\,b_w d$$

The nominal shear reinforcement contribution, Vs, is based on the 45-degree-truss model and where vertical stirrups, (stirrups perpendicular to the axis of member are used (œ = 90)

The ACI 318-95 limits V_s to $0.67\sqrt{(f'_c\, b_w\, d)}$. In addition, a minimum amount of web reinforcement, Av (min.), has to be provided if the applied shear force, Vu, exceeds half of the factored inclined cracking shear, φ (0.5Vc).

$$Av(mm) = \frac{bws}{3f_y}$$

The stirrups are unable to resist shear failure unless they are crossed by an inclined crack. For this reason .ACI Section-11-5-4-1 sets the maximum spacing of

References

ACI 440.2R, 2008, "*Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening of Concrete Structures,"* American Concrete Institute

Chu kia (1998). "*Reinforced concrete design*".

Carlo Pellegrino (2009). "*Flexural Strengthening of Reinforced Concrete Beams with Prestressed FRP*".

Feras alzzoubi a, Zhang and Zheng-liang 29 April (2007)." *Shear strengthening of pre-damaged reinforced concrete beams with carbon fiber reinforced polymer sheet strips*", Vol. 6 No. 4

Gamage, J.C.P.h,wong, M.B & Al mahidi R. (2005)."*Performance of CFRP strengthened concrete members under elevated temperatures*".

H. K. Lee† & S. K. Ha *September* 22 (2008). "*Finite element analysis of shear-deficient RC beams strengthened with CFRP strips/sheets*".Vol. 30, No. 2

Jayabrakash, (2006). "*Shear strengthening of reinforced concrete beams using externally bonded BI- directional carbon fiber reinforced polymer*".

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Khalifa, A.M. (1999). "*Shear performance of reinforced concrete beams strengthened with advanced composites*.University of Missouri-Rolla: ph.D.Thesis.

Liu Zihong,27 July 2007) "*Testing and analysis of a fiber reinforced polymer*".

Manfredi Gaetano and Marisa Pecce 30 August (2006). "*Durability issues of FRP rebars in reinforced concrete members*".NO. 857–868

Mohamed (2009). "*Finite Element Modeling o Reinforced Concrete Beams Strengthened with FRP Laminates*". Vol.30 No.4 (2009), pp.526-541

Nabil F. Grace (May-June 2001)."*Strengthening of negative moment region of reinforced concrete beams using carbon fiber- reinforced polymer strips*". NO. 98-S33

Nadeem seddique (October 2009)."*Experimental investigation of RC beams strengthened with externally bonded FRP composites*".

Norris (1997). "*Analysis of Retrofitted Reinforced Concrete Shear Beams using Carbon Fiber Composites*".

Sikh kimia (2009). "*Sikadar-330,2- part epoxy impregnation resin Malaysia".*

Vellore Gopalaratnam,(2007). "*Flexure shear response in fatigue of fiber reinforced concrete beams with FRP tensile reinforcement*. Local Centre" .pp 150-153.)

Wang (1995). "*Shear Strengthening of Reinforced Concrete".*

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH